1988

Use of life cycle costing in the development of standards.

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http://hdl.handle.net/10945/23144

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

USE OF LIFE CYCLE COSTING IN THE
DEVELOPMENT OF STANDARDS

by

James M. Underwood

December 1988

Thesis Advisor: Paul M. Carrick

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b. OFFICE SYMBOL (If applicable) Code 54
7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School	
6c. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
USE OF LIFE CYCLE COSTING IN THE DEVELOPMENT OF STANDARDS

12. PERSONAL AUTHOR(S)
Underwood, James M.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Master's Thesis	FROM ______ TO ______	1988, December	63

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Life Cycle; Standard

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Prof. Paul M. Carrick	22b. TELEPHONE (Include Area Code) (408) 646-2939 · 22c. OFFICE SYMBOL Code 54Ca

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Use of Life Cycle Costing in the Development of Standards

by

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1988

ABSTRACT

The study set out to determine how, and to what extent, life cycle costing is used in the development of voluntary consensus standards. It explains how several organizations in the commercial sector develop voluntary standards. Among these organizations was ASHRAE, who is currently developing a standard based on life cycle costing. Standard 90.2 "Energy Efficient Design of New Low-Rise Residential Buildings" prescribes the insulation values for the envelope of a building. The economic methodology was based on marginal analysis by considering an upgraded construction component and then determining the incremental energy cost savings to the incremental modification costs over a specified life cycle period. Questions arose concerning the economic assumptions used in developing the standard. It is recommended that an impact study be performed to evaluate the cost estimating techniques and the basic economic assumptions.

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I. INTRODUCTION

A. GENERAL

This study was undertaken to determine how standards related to construction can benefit from economic analysis based on life cycle costing during their development. The chapters to follow will make reference to telephone interviews and prior work in the area of standardizing construction and the use of economics in developing standards.

Interest in the study was originally generated as a result of a thesis titled <u>Standardizing Construction Between Industry and Government</u> [Ref. 1]. This paper explained how several organizations in the federal government and in the commercial sector develop standards for construction. A portion of this prior study was centered on determining how building codes are developed and to what extent economic analysis was carried out in the development of the codes. The only standard writing organization that was identified as using Life Cycle Costing (LCC) in determining the performance level of the standard was the American Society for Heating, Refrigeration, Air Conditioning Engineers (ASHRAE).

ASHRAE was founded in 1894 and was organized and operated for the exclusive purpose of advancing the arts and sciences of heating, refrigeration, air conditioning, and ventilation. With 53,000 members and 154 chapters worldwide, the society is

able to sponsor research, develop standards, publish technical data, and organize meetings and educational activities for both its members and others professionally concerned with refrigeration processes and the design and maintenance of indoor environments. The society is currently supporting 49 research projects and has published 78 voluntary consensus standards that have been included in building codes worldwide. [Ref. 2]

The chapters to follow will analyze the development of the new ASHRAE Standard 90.2 and the use of economics in its development. But first, it is necessary for the reader to understand what voluntary standards are, and how they relate to building codes. The following will discuss this in addition to the organizations involved with voluntary standard writing and the issue of these codes and standards.

A voluntary standard describes how to make a product or perform a procedure and is developed by voluntary organizations comprised of special interest groups, users, and manufacturers interested in the product or procedure. A building code, however, references voluntary standards and tells where and when to use them. It provides the minimal acceptable standards to safeguard life, health, and property. There are thousands of standards that have been developed through the full consensus procedures for construction related activities. These standards are either developed by voluntary

standards writing organizations or the federal government. [Ref. 1:p. 9]

Voluntary standards are written by committees that voluntarily come together to develop standards. Some of the organizations responsible for this process are the American Society for Testing and Materials (ASTM), Underwriter Laboratories, Inc. (UL), National Electrical Manufacturers Association (NEMA), the American Institute of Steel Construction, Inc. (AISC), and the American Society for Heating, Refrigeration, Air Conditioning Engineers (ASHRAE). [Ref. 1:p. 12]

The organization that is responsible for coordinating the U.S. voluntary standards system is the American National Standards Institute (ANSI). It acts as a clearing house and information center for national and international standards, and the approval organization for American National Standards. ANSI approves standards so long as the issuing agency follows the consensus procedures for deriving a standard that it has promulgated. The procedure includes a two-third's majority rule and all affected parties should be represented with no single interest group dominating the committee. Once a standard is approved by ANSI its cover is marked with the words "American National Standard." The organization that developed the standard then agrees to publish the standard and make it available within six months after it has been approved. Once released, the standard can be adopted by one

or more of the three building codes in the U.S. For example, the International Conference of Building Officials (ICBO) can adopt the standard and it will then be incorporated into the Uniform Building Code (UBC) which is used by municipalities. The municipalities adopt the codes through local ordinances which have the effect of law. The building officials are responsible for enforcing the building code and any amendments made by the local government. [Ref. 3:p. 10]

ANSI does not develop standards, but does provide the method for determining the needs for standards. ANSI has strict procedures in the recognition of a voluntary standard as a national consensus standard. They prescribe the make-up of the committee and also the consensus procedures.

Consensus is an important aspect of the voluntary standard writing process. It is achieved when "substantial agreement" has been reached by those on the committee. [Ref. 3:p. 5] This creates a forum where all interested parties can express their own opinions on the content and level that the standard will be developed. The number of volunteers on a committee varies with the scope of the standard. ANSI prescribes that there should be a minimum number on a committee which will include the producer, user, and general interest groups to ensure consensus. [Ref. 3:p. 5] These can include, and are not limited to, installers and maintainers of the product that will be affected by the standard; a laborer or employee concerned with safety in the work place; an applied research

and testing laboratory representative; an enforcing authority such as an insurance company or inspection agency; special experts in the applied area; and the ultimate purchaser of the product, the consumer.

Consensus is defined as when at least two-thirds of the interest groups agree. Of course, there is an appeals mechanism readily available for the impartial handling of substantive and procedural complaints regarding any action. [Ref 3:p. 7] An example is how ASHRAE conducts their review process. An announcement is made in their sponsored publication on the availability of a draft for public review. Sixty days are allowed for comments to be sent in. If there are no comments, the standard is sent out for printing and publication. If comments are received and have a definite impact on the standard, changes are examined and considered in the consensus process. The 60 day review cycle is once again repeated before the standard is sent to print and publication. [Ref. 4]

Consensus procedures do not require consideration of life cycle costing and effectiveness, i.e., cost benefit analysis, to reach a conclusion. Committees may introduce such considerations but they are not a mandatory part of the deliberation.

B. METHODOLOGY

Life cycle costing is an important technique in choosing between alternatives. Without alternatives there can be no

costs from the point of view of resource allocation decisions. Life cycle costing helps identify the full economic cost of an alternative and facilitates an analytical process to reach a final decision. [Ref. 5:p. 67] There are several different techniques in applying LCC, which will be discussed later.

The primary source of information for the study came from the American Society for Heating, Refrigeration, Air Conditioning Engineers (ASHRAE) Standard 90.2 Draft #3 and a commentary on the development of the standard. This was necessary because the amount of written material on the use of life cycle costing in the development of a standard is very limited and general in nature. A series of questions were developed for use in the interviews. An interview was considered to be preferable over a questionnaire due to the nature of the subject. This served as a base from which to concentrate on areas that were unclear during initial interviews or that were unanswered. The following is a list of the questions asked during the interviews.

1. Are economic benefits and costs considered during the establishment of the various types of standards used in construction?

2. Is life cycle cost analysis being used to determine the level that a standard is written to?

3. Have comparisons or impact studies been performed to show the benefits of the new method of standard writing over the old?

4. What types of standards can benefit from the use of life cycle cost analysis in their initial development?

5. Once a standard is developed, how is it disseminated to the public?

6. What are some of the basic assumptions when using life cycle costing?

C. ORGANIZATION OF THE STUDY

It was considered important that the technique of life cycle cost analysis be described in depth so that the reader will have a good understanding of what is involved in the process. Chapter II is therefore devoted to explaining how life cycle costing is used in defining the economic impacts of competing alternatives and then evaluating the results to make a justifiable decision. Chapter III will describe the historical development of ASHRAE Standard 90.2 and show how life cycle cost analysis is used in its development. Chapter IV presents the outcomes and findings of this analysis and the interviews. The progress that has been made to date in the development of this standard is also presented. In addition, a discussion will be developed of the possible standards which could benefit from life cycle cost analysis.

II. LIFE CYCLE ESTIMATING PROCEDURES AND METHODOLOGY

A. GENERAL

Life cycle costing involves defining, and then evaluating, economic impacts of different alternatives over a defined period of time. Present and future costs are estimated and classified as either initial costs, recurring costs, or nonrecurring costs. It might appear that initial costs are the same as nonrecurring costs, but this is not always true. Once these costs are defined they can be translated to a common point in time by reducing the stream of costs to a single number, where costs which are projected to occur in the future are discounted. This is the basis for the Present Value method, which is highly recommended for decision criteria. [Ref. 6:p. 14] All significant costs are considered for the calculations of the designated life cycle. A formal definition of life cycle costing is:

> An economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars. [Ref. 7:p. 217]

But in life cycle costing there exists a need to adjust the estimated cost values by the year in which thay will be spent. Many problems that are central in decision alternatives involve a choice between doing something now and doing it later. The discount rate is an important parameter in representing the present value of future costs. For

example, in evaluating a proposed construction project, the present value of the benefits is compared with the present value of the costs, and the project is only carried out if the benefits exceed the costs. The present value of the costs and benefits depend on the discount or interest rate used. Increases in the discount rate decrease the possibilities of the acceptance of the project. This is because initial costs can be extremely high early in construction while benefits occur later in the life of the project. Clearly, the rate of discount is an important parameter in the present value calculations. There are many discount rate concepts such as: market interest rates, marginal productivity of investment, corporate discount rate, the government borrowing rate, and the social opportunity cost of capital. The proper rate to choose is the rate, when applied to future costs, yields their actual present value. [Ref. 6:p. 98]

To further compound the matter, inflation must be considered since it has a significant impact on the rising costs of products and services and reduces the purchasing power of the dollar. The inflation rate has bounced all over the scale since the early 1900's. In order to accurately compare design or project alternatives the present and future costs must be brought to a common point in time.

There are many economic techniques that can be used in the analysis of life cycle costing which will depend on the situation and the special needs in understanding the choice

of alternatives. Two methods, that are often used to achieve commonality, will be discussed. They are the Present Worth Method and the Annualized Method. Each method of application will be discussed and followed by an example.

1. Definitions

The following is a list of brief definitions of the terms to be discussed in the following methods and concepts.

- Initial costs--costs associated with initial development or start of a project which do not require discounting. These are sometimes referred to as "first costs."
- Recurring costs--costs that recur on a periodic basis throughout the life of a project.
- Nonrecurring cost--a cost that occurs, or is expected to occur, only once or on an infrequent basis.
- Discount factor--the factor for any specified discount rate that changes an expected cost in any future year into its present value.
- Escalation rate--the rate of inflation above the general devaluation of the purchasing power of the dollar.

B. METHODS OF APPLICATION

1. Present Worth Method

The present worth method reduces all costs, expenditures, revenues, and receipts to a present point in time. The following formulas convert recurring and nonrecurring costs:

Nonrecurring Costs (equation defining equivalency of present worth and future worth of $1)

$$PW = F \frac{1}{(1 + i)^n}$$

where:

PW = present worth of a sum of money;

i = interest rate per interest period;

n = number of periods;

F = future worth.

Recurring Costs (equation defining a $1 outlay at end of each year for n years)

$$PWA = A \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

where:

PWA = present sum of a sequence of consecutive payments or receipts;

A = end of period payment or receipt in a uniform series.

Since the calculation of present worth is often considered "discounting" many economists refer to the interest rate in these calculations as the discount rate. This is the minimum rate of return one is willing to accept for investment purposes or the alternative opportunity cost of an investment. This rate is established after consideration of several factors. Some of these are:

- The expected return of investing needs to be greater than the cost of the money borrowed. (Benefits > Costs.)
- The risk of total loss has a direct affect on the interest rate.
- Decide whether the decision to choose an alternative will be based on costs and revenues before or after taxes.

The federal government through OMB Circular A-94 has established 10 percent as the interest rate for life cycle cost studies. This may not be the most ideal figure for all calculations but is prescribed since it best represents an estimate of the average rate of return on private investment, before taxes and after inflation. The circular also included an attachment containing discount factors for the discount rate of 10 percent for each of the years from one to 50 to assist in calculations. [Ref. 7:p. 20] The number of interest periods (n) is usually expressed in years. A time period of 10 to 30 years is considered adequate for estimating expenses into the future.

This is illustrated in Figure 1 by plotting an annual cost for 100 years discounted to present worth at a 10 percent discount rate. You will notice that the area under the curve represents the total present worth amount and that 85 percent of the total project life cost is represented in the first 25 years. [Ref. 7:p. 22]

Recurring costs can also experience another phenomenon known as price escalation. This rate is not the same as the inflation rate, but the rate above the general devaluation of the purchasing power of the dollar. Therefore the formula must represent both the discount rate and the differential price escalation.

Energy costs provide a good example of how price escalation does not necessarily follow the rise and fall of

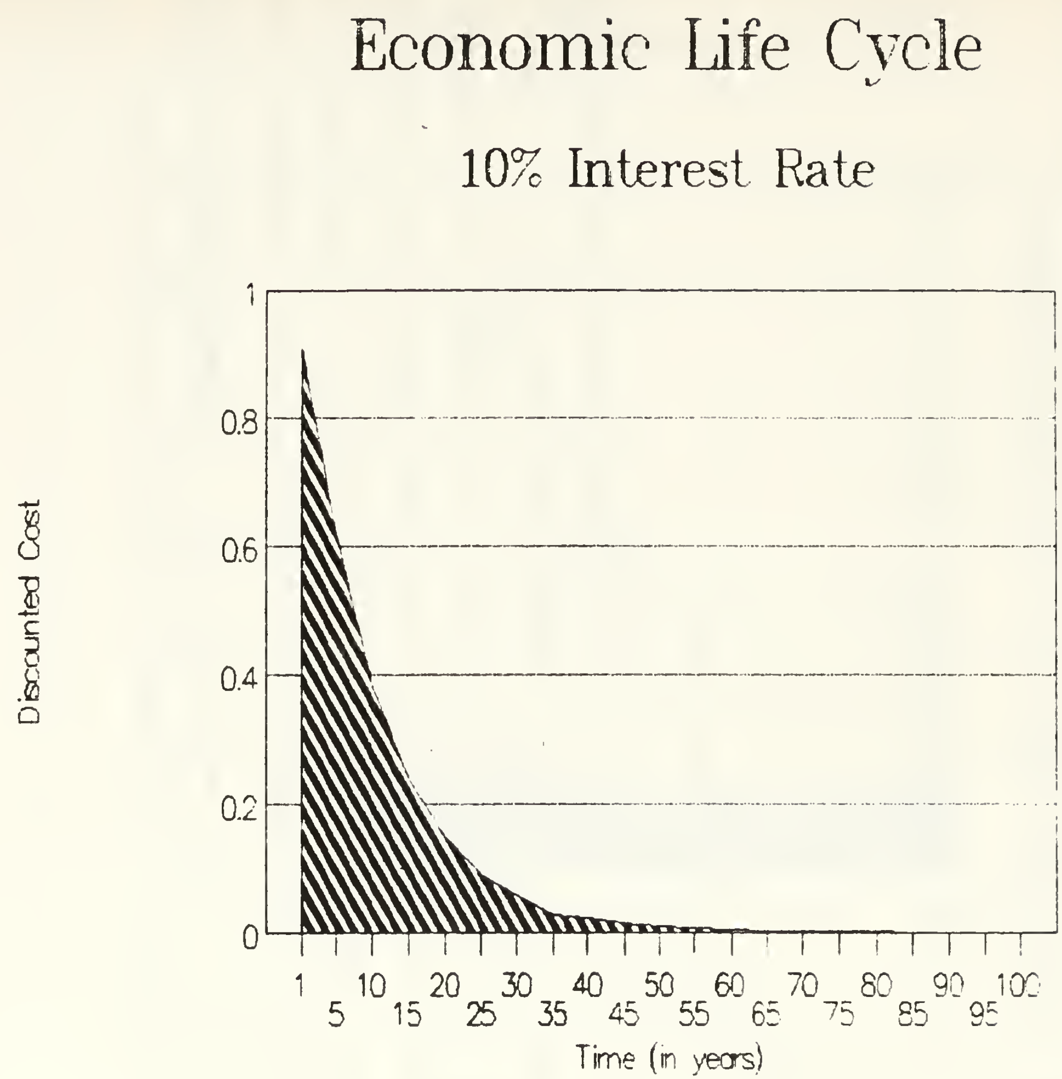

Figure 1. Economic Life Cycle

the national inflation rate. Figure 2 provides a graphic illustration with data collected by the National Aeronautics and Space Administration (NASA) in February 1979. [Ref. 7:p. 20]

Since energy cost escalation and inflation fluctuate at different rates, the formula for the Present Worth of recurring costs must be modified. This removes the effects of inflation and the anticipated price changes.

$$P = A\,\frac{[(1+e)/(1+i)]\{[(1+e)/(1+i)^{n} - 1)\}}{[(1+e)/(1+i)] - 1}$$

where:

e = escalation rate.

The following illustrates the use of the Present Worth method in a decision between two alternatives. A taxi cab service must make a decision to buy either a car produced by Ford of Dodge. Each has a different initial cost, maintenance cost, and replacement time frame. Though it may seem that the obvious choice would be the Dodge due to the low initial cost, but this is not necessarily so. A summary table is provided at the end of the example indicating the proper choice.

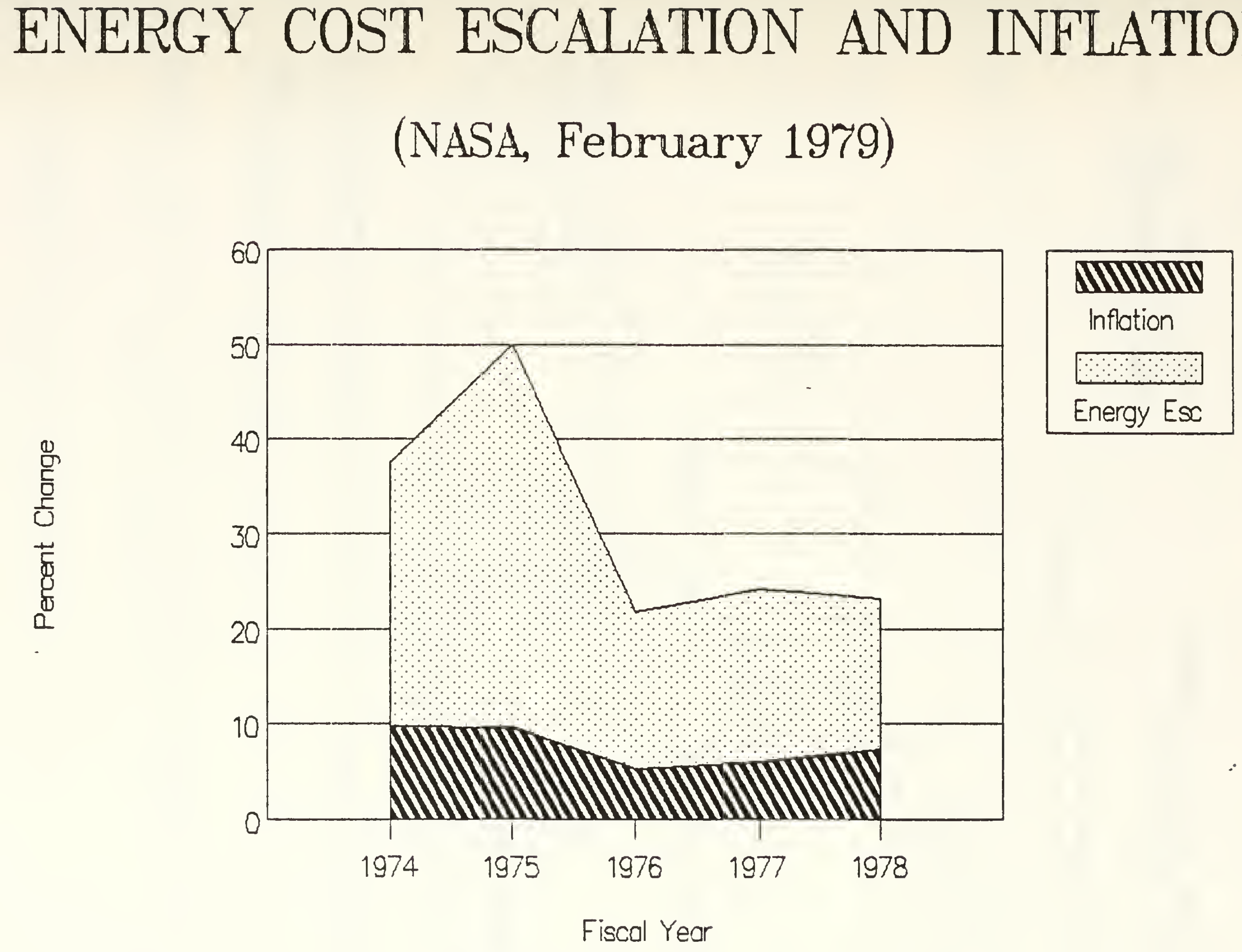

Figure 2. Energy Cost Escalation and Inflation

a. Example: Present Worth Method

Taxi Cab Fleet	Dodge	Ford
Given:		
Initial Cost (10 cars)	$80,000	$100,000
Annual Maintenance	6,000	3,000
Useful Life	3 years	5 years

Interest Rate = 10%
Life Cycle of Study = 15 years

Solution:

<u>Recurring Cost</u>

(Dodge Maintenance)

$$PWA = A \frac{(1 + i)^n - 1}{i(1 + i)^n} = 6,000 \frac{(1 + .10)^{15} - 1}{.10(1 + .10)^{15}} = \$45,636$$

(Ford Maintenance)

$$= 3,000 \frac{(1 + .10)^{15} - 1}{.10(1 + .10)^{15}} = \$22,818$$

<u>Nonrecurring Cost</u>

(Dodge Replacement) Year 3

$$PW = F \frac{1}{(1 + i)^n} = 80,000 \frac{1}{(1 + .10)^3} = \$60,105$$

Year 6 $$= 80,000 \frac{1}{(1 + .10)^6} = \$45,157$$

Year 9 $$= 80,000 \frac{1}{(1 + .10)^9} = \$33,927$$

Year 12 $$= 80,000 \frac{1}{(1 + .10)^{12}} = \$25,490$$

Year 15 $= 80{,}000 \dfrac{1}{(1 + .10)^{15}} = \$19{,}151$

Subtotal = $183,830

(Ford Replacement) Year 5

$$= 100{,}000 \frac{1}{(1 + .10)^{5}} = \$62{,}092$$

Year 10 $= 100{,}000 \dfrac{1}{(1 + .10)^{10}} = \$38{,}554$

Year 15 $= 100{,}000 \dfrac{1}{(1 + .10)^{15}} = \$23{,}939$

Subtotal = $124,585

Summary Table

	Dodge	Ford
Initial Cost	$80,000	$100,000
Recurring Cost	45,630	22,810
Nonrecurring Cost	183,830	124,585
	-------	--------
Total Present Worth	$309,460	$247,395

************** Select the Ford Car **************

* Now assume that maintenance experiences a price escalation of 5% per year.

<u>Recurring Cost Escalating</u>

$$\text{Dodge} = 6000 \frac{[(1 + .05)/(1 + .10)]\{[(1 + .05)/(1 + .10)]^{15} - 1\}}{[(1 + .05)/(1 + .10)] - 1}$$

$$= \$63{,}292$$

$$\text{Ford} = 3000 \frac{[(1 + .05)/(1 + .10)]\{[(1 + .05)/(1 + .10)^{15} - 1\}}{[(1 + .05)/(1 + .10)] - 1}$$

$$= \$31,644$$

Summary Table

	Dodge	Ford
Initial Cost	$80,000	$100,000
Recurring Cost	63,292	31,644
Nonrecurring Cost	183,830	124,585
	-------	--------
Total Present Worth	$327,122	$256,229

************** Select the Ford Car ****************

2. <u>Annualized Method</u>

The Annualized Method is essentially the same as the previous method except initial, recurring, and nonrecurring costs are converted to a series of annual payments. This is used to express all of the life cycle costs as an annual expenditure. The results will not change in the choice of alternatives, but the costs are distributed throughout the life of the project as an equivalent annual amount. However, initial costs and nonrecurring costs must be converted to a present worth amount as in the earlier method, and then, converted to an annual payment with the following equation.

$$A = P \frac{i(1 + i)^n}{(1 + i)^n - 1} = PP$$

where:

A = annualized cost;

P = $1.00;

PP = periodic payment factor.

All costs are expressed in present worth or equivalent dollars and therefore, the sum of the initial, recurring, and nonrecurring costs will equal a project's total life cycle cost.

The following illustrates the use of the Annualized Method in a decision between two alternatives. A school must decide whether to purchase a new boiler system from Ace Equipment Company or Industries Incorporated. As in the previous example, costs and equipment are significantly different for each company. A summary of the results follows the calculations for the annualized life cycle costs.

a. Example: Annualized Method

Boiler System	Ace Equipment Co.	Industries Inc.
Given:		
Initial Cost	$7,000	$8,500
Operating Cost per Year	200	100
Useful Life	6 years	9 years

Interest Rate = 12%
Life Cycle of Study = 18 years

Solution:

<u>Initial Cost</u>

(Ace costs annualized)

$$A = P \frac{i(1 + i)^{n}}{(1 + i)^{n} - 1} \qquad = \quad 7000 \frac{.12(1 + .12)^{10}}{(1 + .12)^{10} - 1} \quad = \quad \$\ 965$$

(Industry costs annualized)

$$= 8500 \frac{.12(1 + .12)^{10}}{(1 + .12)^{10} - 1} = \$1172$$

Nonrecurring Cost

(Ace replacement costs) Year 6

(find present worth)

$$P = F \frac{1}{(1 + i)^{n}} \qquad = 7000 \frac{1}{(1 + .16)^{6}} = \$3,546$$

(then annualize)

$$A = P \frac{i(1 + i)^{n}}{(1 + i)^{n} - 1} \qquad = 3456 \frac{.12(1 + .12)^{10}}{(1 + .12)^{10} - 1} = \$489$$

Year 12

(find present worth) $= 7000 \dfrac{1}{(1 + .12)^{12}} = \$1,796$

(then annualize) $= 1796 \dfrac{.12(1 + .12)^{10}}{(1 + .12)^{10} - 1} = \$247$

* The factor in annualizing the present worth amounts remains constant for the rest of the calculations.

(Industry replacement cost) Year 9

(find present worth) $= 8500 \dfrac{1}{(1 + .12)^{9}} = \$3,065$

(then annualize) $= 3065(.137937) = \$422$

Summary Table

	Ace Equipment	Industry Inc.
Initial Cost	$965	$1,172
Operating Cost	200	100
Replacement Yr 6	489	0
Replacement Yr 9	0	422
Replacement Yr 12	247	0
	----	------
Total Life Cycle Annual Cost	$1,901	$1,694

*********** Select Boiler from Industry Inc. ***********

C. ESTIMATING METHODS

Probably the most important element of life cycle costing is the cost estimate. To arrive at the optimal alternative in the decision process, one must be able to accurately estimate the costs. There are two common methods for estimating costs and there has been considerable discussion on which provides the most accurate estimates. The first is the parametric approach which uses historical costs from previous projects. Unit costs are used as the basis for the calculations, by increasing or decreasing quantity, size, weight, or other factors for the project. Usefulness of this method alone is sometimes limited. Since this approach does not enter into the finite detail of the smallest cost elements, major cost drivers are not always identified, resulting in some degree of inaccuracy. The second approach, the engineering or statistical, requires that the project be broken down into its smallest cost elements and subelements where man-hours and materials can be estimated and then accumulated to arrive at a total cost estimate.

Both of these estimating methods are satisfactory for estimating costs. To decide on one, or the other, depends on the project or process that is being evaluated, the amount of historical information available, and the time allowed for preparing the estimates. Experience has shown that the most credible and accurate estimates are arrived at after extensive analysis is made of the project and its elements. Since this study is concerned with construction standards, the following discussion will concern itself with those costs normally encountered in preparing a cost estimate and the generally accepted approach for determining them. [Ref. 8:p. 6]

1. <u>Initial Costs</u>

Initial costs are referred to as the first costs in the development of a facility, project, or a production run of an end product. They can include design, legal, and professional fees; equipment and property cost; furnishings and all materials for construction that adds to the capital investment. Since these costs must be estimated, a typical source for this data is contained in various unit price publications. Costs are arranged in a logical format containing both material and labor costs to install and are readily available. [Ref. 7:p. 30]

2. <u>Energy and Operating Costs</u>

To determine energy and operating costs, the designer must first estimate the energy consumption levels of various

types of equipment. Four estimating methods available are discussed below.

a. Equivalent Load Hours

Data from previous projects are sometimes the best information to estimate the equivalent number of full load hours of operation per month for various types of equipment. Once determined, these hours are multiplied by the hourly full load rate of energy consumption. This will yield the required energy consumption and can be more accurately reflected by using average load efficiency instead of full load efficiency for equipment that is not used continuously.

b. Degree Day

Used in the early stages of design, this technique defines the heating requirements for a 24-hour period and then computes the energy consumption to meet the load. This is an empirical method based on statistical samples of numerous facilities but can result in minor errors when dealing with a specific facility, building, or structure.

c. Hour by Hour

Hour by Hour computes an instantaneous building load, residual stored load, and the resulting Heating, Ventilation, and Air Conditioning (HVAC) system performance for each hour of the year. Monthly or yearly consumption can be easily determined for cost calculations. Drawbacks of this method are the large amounts of data that must be compiled. This usually requires the use of a computer.

d. Outside Temperature Bins

Based on the principle that the load of a Heating Ventilation Air-Conditioning (HVAC) unit is directly related to outside temperature, the energy consumption is computed at different outside temperatures and consumption for other levels is extrapolated. Accuracy is dependent on the number of temperature calculations taken and the specific use of the HVAC unit.

Once consumption requirements are calculated, an energy model is helpful in developing a basic energy budget or to indicate where potential savings exist. Energy models usually transform data into energy units (EU) instead of dollars, but can easily be translated depending on the type of fuel chosen for the equipment. Energy models have been developed by several agencies including ASHRAE and DOE. [Ref. 7:p. 42]

3. <u>Maintenance Costs</u>

These costs contribute to a significant portion of the life cycle costs but inherently have the least research and documentation available. Figure 3 illustrates a comparison of costs that make up the total cost of a typical building construction. Although these amounts and proportions differ for other applications, they give a good representation for average construction.

When making an alternative decision, it is essential that each decision be based on comparable levels of

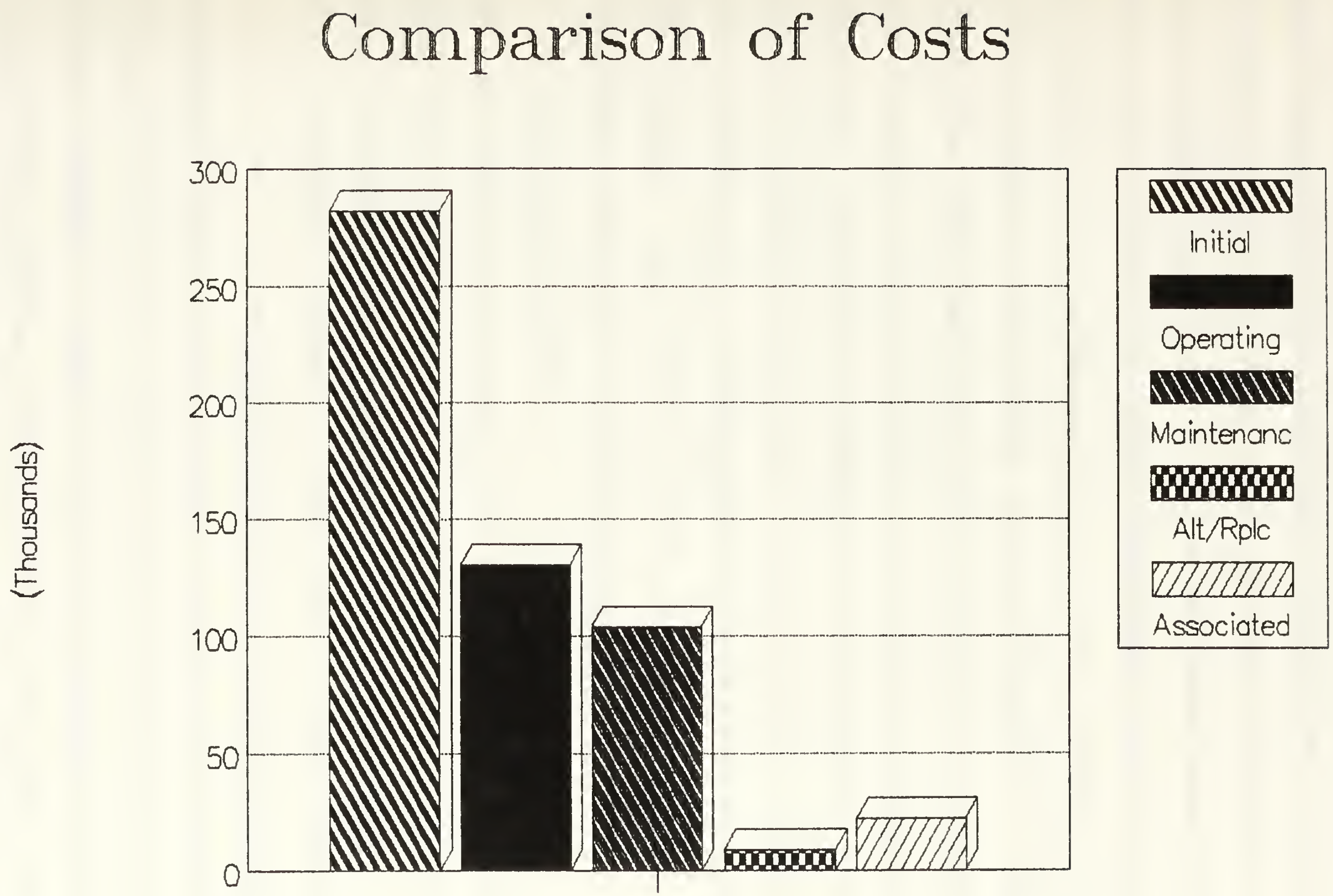

Figure 3. Comparison of Costs

maintenance. Many of the components that make up a facility can have a shorter life span than the overall planned life of the facility. Consequently, replacement and maintenance costs may be a major part of the life cycle cost of a facility. Some of the most common measures in estimating costs include mean time between maintenance (MTBM) and is the average time between maintenance actions for a specified period or for the life cycle. Another is mean preventive maintenance time (MPMT) which is the mean or average elapsed time required to perform scheduled and preventive maintenance on an item. This can include calibration of equipment, servicing, inspection, and possibly overhaul during the actual operation of the equipment or during scheduled down time. Since this type of work is very labor intensive and can span lengthy time periods, the data can age quickly and require an escalation factor to make the data useful for future computations. A source for this type of data is readily available from the Building Owners and Managers Association International which contains statistical cost increases for various labor categories and areas of the country. [Ref. 7:p. 50]

4. Alteration and Replacement Costs

Alteration costs are associated with the anticipated modernization or changing of a building or facility to provide a new function while replacement costs are those one-time costs to be incurred in the future to maintain the original function of the facility. When designing a facility one must

be aware of the life cycle of each subsystem and its cost to make an accurate decision when reviewing alternatives. In addition, one must take into consideration the changing use of the facility and determine if it is cost effective to design it for future alterability. This can reduce future alteration costs and should be considered for each alternative. Information is available that provides select life cycle costing data in the areas of architectural, mechanical, electrical, and site. When using this data one must exercise caution. The data are based on certain assumptions; that there are established preventive maintenance plans, and inventories for spare parts are available. Other factors that might influence this information is labor rates, contracted work in lieu of in-house work, climatic conditions, and managements emphasis on maintenance. [Ref. 7:p. 56]

5. <u>Associated Costs</u>

Sometimes the only costs considered on a project are those that have been discussed above. But what about costs such as staff salaries, down time during construction due to unique building techniques, denial of use, and possibly many others? These can be essential if they have a definite impact on deciding between alternatives. Items like functional use costs (staff salaries) can be difficult to determine due to their qualitative parameters. Since these costs can contribute to a sizeable portion of the overall life cycle costs they must be dealt with through a comparison approach of costs at

comparable performance levels. Even though this seems difficult to accomplish, decisions must be made whether to include them in the life cycle cost study on the premise that they may affect the decision outcome in the choice of alternatives. [Ref. 7:p. 64]

D. SUMMARY

This section has discussed the elements of life cycle costing which included the methods of applicaton, discount and escalation rates, and some of the methods used in estimating costs. Life cycle costing techniques can be used for many purposes other than the choice between competing project alternatives. It can be used in financial planning and budget preparation, selection of component equipment, types of construction contracts and even preventive maintenance programs. The process can be modified for other applications to suit its particular needs. A new approach is its application to the writing of construction standards. The method of applying life cycle costing is analyzed in the following chapter on the review of ASHRAE Standard 90.2.

III. ANALYSIS OF ASHRAE STANDARD 90.2

A. HISTORICAL DEVELOPMENT

During the early 70's, energy consumption became a great concern due to the fuel shortages experienced at that time. Committees were appointed to investigate alternative fuel sources and ways of reducing present energy consumption. One committee in particular was formed by the American Society for Heating, Refrigeration, Air Conditioning Engineers (ASHRAE) to develop a standard for the energy efficient design of new low-rise residential buildings which would encompass not only safety and welfare of the individual but also energy considerations. The original publication, Standard 90A-1980 "Energy Conservation in New Building Design," was published in 1980. The Planning, Policy and Interpretations Subcommittee of ASHRAE schedules its periodic five year review of the standard for revision, withdrawal, or reaffirmation. The existing standard was considered to contain outdated technology, and required an upgrade to consider the effects of cooling which had never been considered in any prior standard. [Ref. 9] The standard itself was very difficult to implement by the building code officials and contractors, since it was written solely by engineers for engineers. But the difficulties that were encountered during the committee deliberation process, resulted in pushing the date for

revision of the standard to 1989. The committee was composed of 13 voting members and 30 non voting members. Engineers, designers, manufacturers, and public officials were represented on the committee. A list of both voting and non voting members is contained in Appendix A. The meetings occurred over a period of four years. The initial distribution list for the working drafts consisted of approximately 250 interested parties. [Ref. 4]

The initial committee meetings were concerned with the approach that would be used in development. Three essential points were agreed on:

- The standard must be simple to understand and easy to use.
- The standard must have an underlying methodology that provides technical accuracy.
- The standard must incorporate economic considerations to ensure the criteria are justifiable.

Other items that formed the basis of the design concerned construction type, load savings, weather data, cost data, heating and cooling space conditioning equipment, economic model, and the national energy model. Each of these will be briefly discussed to provide insight into the development process and reasoning for the methodology undertaken by the committee. The full committee formulated the basic strategy while panels were established to develop the technical content. The following discussion will detail the basic elements in the committee's formulation of the standard. [Ref. 10:p. 4]

1. <u>Construction Type</u>

A decision was made early on to have two distinctive specifications. One, which is discussed in this thesis, applies to new low-rise residential buildings and the second applies to large commercial buildings labeled ASHRAE Standard 90.1. Before the "load savings," which is the monetary value of the reduction in energy consumption, of any particular construction technique could be calculated, definitions of typical constructions for ceilings, walls, floors, band joists, doors, infiltration, and fenestration had to be determined. For each of these construction types a U-value was calculated indicating its thermal efficiency. A U-value is the measure of thermal transmittance through a substance which is the inverse of the R-value measure for insulation. Since building components are an accumulation of several materials, including air spaces and surface films, the overall conductance or U of a construction type is needed in heat-transfer calculations. This factor is defined as the number of BTU's that will flow in one hour through one square foot (SF) of the structure from air to air with a temperature differential of one degree F. [Ref. 11:p. 1563] Values of U, between zero and one were determined experimentally for each type of construction. As the resistance to thermal transfer increases, the U value decreases. In addition, three types of foundations were considered including the insulation location of each; those being basements, crawl spaces, and slab

constructions. The committee decided to adopt the analysis published by Paul Shipp, "Basement, Crawlspace, and Slab-On-Grade Thermal Performance" [Ref. 10:p. 17], due to his approach in experimental verification of two dimensional finite difference analysis procedure. [Ref. 10:p. 10]

2. Load Savings

The technical basis on which load savings were estimated was a simplified application of the Department of Energy, DOE-2 computer program, which is a public domain software. This simplified approach was the Program Energy Analysis for Residences (PEAR) program developed by Lawrence Berkeley Laboratories (LBL) of California which uses the massive data base of the DOE-2 program. A 1200 square foot (SF) prototypical house as defined in a National Bureau of Standards (NBS) report, "Economics and Energy Conservation in the Design of New Single-Family Housing" [Ref. 10:p. 10] was used to evaluate 15 different construction modifications as listed in Table 3.1, Appendix B, and analyzed in 14 cities. As incremental modifications were made, heating and cooling load reductions were recorded and compared to the NBS report. Differences in the test reports were attributed to variances in thermostat set points, the rates of natural ventilation and the assumption of internal load profiles. Based on the high degree of comparison between actual tests and the NBS report, the PEAR results were accepted by the committee and used as input for the data base. [Ref. 10:p. 10]

To show a relationship between two or more variables, regression analysis is used as a modeling method to find a relationship between the variables. It is a very useful and perhaps the most commonly employed method of data analysis. This method was used in the PEAR program to regress the load savings on the temperature variable. In order to generalize these results so they could be used as source data for different areas of the country, a temperature or weather variable needed to be identified with the corresponding reductions in energy consumption due to the incremental modifications. The heating load savings for different construction types were first regressed on the heating degree day base variable. Several bases were selected, resulting in 65 degree F having the highest correlation indicated by the high R-square values as shown in Appendix B. The same procedure was conducted for the cooling load savings but cooling degree hours was used as the variable to regress upon. This was due to earlier experiments which showed a high correlation as indicated by their R-square values and could be obtained by using this variable over heating degree days. Base 74 degree F (CDH74) was finally selected due to their higher correlation levels achieved for the largest number of construction types. Table 3.1, Appendix B, displays a complete summary of the statistical correlations for the different construction types. [Ref. 10:p. 14] The equations for generalizing the load savings are:

$$\text{Heating Load Savings} = \text{Beta}_{h,i} * \text{HDD65} \qquad (3.1)$$

$$\text{Cooling Load Savings} = \text{Beta}_{c,i} * \text{CDH74} \qquad (3.2)$$

where:

HDD 65 = Heating Degree Days to Base 65 degree F;

CDH 74 = Cooling Degree Hours to Base 74 degree F;

$\text{Beta}_{h,i}$ = Slope of line for heating for the i-th construction;

$\text{Beta}_{c,i}$ = Slope of line for cooling for the i-th construction;

i-th = Iterative construction.

At this point a distinct Beta was required for each incremental construction modification. Next it was necessary to generalize the constructions to allow interpolation. This was accomplished by comparing the correlation between the Betas to the corresponding change in U values for the incremental modifications. [Ref. 10:p. 11]

$$\text{Beta}_{h,i} = \text{delta U} * \text{HLF}$$

$$\text{Beta}_{c,i} = \text{delta U} * \text{CLF}$$

where:

delta U = Incremental U value for construction modification;

HLF = Heating Load Factor;

CLF = Cooling Load Factor.

The slopes of the linear fits between delta U values and the corresponding Betas are the Heating and Cooling Load Factors. These factors are listed in Table 3.2, Appendix B. Combining Equations 3.1 through 3.4 yield the final form which is used for estimating reductions in the heating and cooling loads. [Ref. 10:p. 15]

Heating Load Savings = delta U * HLF * HDD65

Cooling Load Savings = delta U * CLF * CDH74

All of the heating and cooling load factors that were developed are shown in Table 3.2, Appendix B.

3. <u>Weather Data</u>

Weather data were collected in order to use this standard. Information was collected from NOAA weather data for 3,349 locations. If a specific location is not available, choosing the closest recorded site is sufficient for compliance to the standard. [Ref. 10:p. 20]

4. <u>Cost Data</u>

Since historical data might not be consistent or current an ASHRAE funded research project was awarded to the National Association of Home Builders Research Foundation to develop the cost data for the basis of energy savings calculations. The data reflected the end cost to the consumer, pertaining to fuel cost and first costs of materials. In addition, members of the committee provided

additional information to the cost data base in respect to their individual expertise in selected areas. [Ref. 10:p. 21]

5. Heating and Cooling Space Conditioning Equipment

An assumption was made that HVAC equipment in a residence would be properly sized for its load capacities. Again, a 1200 square foot single story residence was analyzed to determine the design heat loss and the heating energy consumption as construction modifications were made. Specifications for equivalent full load hours for heating and cooling are given in Appendix C. [Ref. 10:p. 25]

6. Economic Methodology

The committee decided to use marginal analysis by considering an upgraded component and then determining the incremental cost savings to the modification costs, or in other words, a modified life cycle costing model. Simply stated this meant that the incremental energy savings due to an increased level of conservation would be equal to or greater than the incremental first costs associated with that level of conservation. [Ref. 10:p. 5]

The costs that the committee looked at were the marginal costs for an upgrade. For example, they would start with a 2" X 4" wall, with interior and exterior sheathing and siding with no insulation. This established the basic element for the construction and would carry over to the incremental modifications. These initial costs would not change as a function of the insulation in the wall cavity and therefore

would be set to a value of zero cost. As insulation was added to the wall, the insulation value was calculated along with its modification costs for each iterative construction modification. At this point the committee used a method of life cycle costing for determining the present value of the energy load savings. They assumed a 30 year life cycle and took the monetary value of the energy savings due to the incremental changes in the wall constructions for each year, then discounted them back to a present worth. Equations and definitions of terms are given in Appendix D. [Ref. 9]

A distinct advantage that the committee realized in using this economic methodology was the ability to represent various economic techniques in a consistent set of equations. This was the reason for developing a scalar quantity to represent Sh and Sc in Appendix D. [Ref. 10:p. 5] In developing the scalars, the committee decided to modify the present worth factors to take into account the tax bracket of the homeowner, mortgage rates, the points to pay on the loan, and the discount rate. What they found was a factor to multiply on both sides of their general equation; one, which applied to the energy cost savings and the other to the incremental construction costs. The equation was then manipulated to get both scalars in a ratio on one side of the equation. It was then possible for the committee to test the sensitivity of the economic assumptions listed below:

- no down payment on extra loan amount;
- 12% fixed rate mortgage;
- 1% loan placement fee (points);
- 10% discount rate (after tax equivalent);
- 30% income tax rate (state and federal combined).

The committee did not want to get locked into a position in which they would have to defend specific discount or fuel escalation rates. It was determined that the scalar ratio was insensitive to the numerous, though minor, changes made to the input variables. This enabled the scalar ratio to be independent of the economic model. The scalars by themselves could not resolve the economic debate but were successful in simplifying the analysis and enhance the understanding of the impact of various ideas or methodologies. Final consensus by the committee was reached when the scalar ratio was adopted as an independent variable in the analysis of the National Energy Model. [Ref. 9]

7. National Energy Model

To observe the sensitivity of the scalar ratios in response to the input variables measured across the different climates of the country, the National Energy Model was developed. The major elements that make up this model are detailed in the following discussion. [Ref. 10:p. 21]

- Define a typical single family residence--A typical home was a L-shaped single story residence with fenestrations making up 15% of the floor area distributed uniformly on all four orientations and two doors. The foundation type consisted of a crawl space.

- Select numerous locations to calculate energy consumption --In order that the national energy consumption would be indicative of new construction, 73 locations were indicated as having significant new housing construction starts.

- Start with a low scalar and calculate national consumption.

- Increment scalar ratios and recalculate national consumption.

Numerous iterations of the model were conducted starting with a scalar ratio of two and increasing to 30. For the analysis, both the heating and cooling scalar ratios were set equal to each other at each step. Based on the results, the committee arrived at a scalar ratio of 18 to represent the heating and cooling parameters for the standard. [Ref. 10:p. 21]

The committee was forging new ground by considering the standard from an economic view. It is evident that it was a long painstaking process to arrive at a consensus in many of these matters. The ASHRAE Standard 90.2 represents a significant development in establishing new standards and also in revising current standards and specifications.

B. ORGANIZATION OF THE STANDARD

The standard is divided into eight sections. Each part will be briefly discussed to help the reader to quickly identify pertinent sections during review of ASHRAE Standard 90.2.

- Section 1, Purpose--To provide design requirements for the new construction of energy efficient residential buildings.

- Section 2, Scope--The standard pertains to new "residential dwelling units" which include single or multi-family structures of up to three stories above grade. Other items included:

  - Building envelope;

  - Heating & air conditioning equipment and systems;

  - Overall building design alternatives;

  Items not included:

  - Operations, maintenance, and use of the building;

  - Portable products such as appliances;

  - Residential electric service;

  - Lighting requirements.

- Section 3, Definitions--All terms that are unique to the standard are defined in this section.

- Section 4, Exterior Envelope Requirements--This section contains equations, charts, and tables intended for defining the minimum thermal transmittances or performance requirements for the exterior air envelope around the residential dwelling.

- Section 5, Heating, Ventilating and Air-Conditioning (HVAC) Systems and Equipment--The requirements for effective energy utilization are defined along with the minimum efficiency levels of the HVAC system equipment. Items that are discussed in particular are:

  - Design load calculations;

  - Sizing of air ducts and piping;

  - Equipment selection;

  - Installation techniques;

  - Control system design.

- Section 6, Service Water Heating--The purpose of this section is to provide criteria for design and equipment selection of water heaters, storage tanks, pumps, and piping that will produce energy savings.

- Section 7, Alternative--Prescriptive Requirements for Exterior Envelope and Space Conditioning Equipment--Since there is an interaction between improvements in the exterior envelope and improvements in efficiency of space conditioning equipment, this section was formed to provide alternate prescriptive requirements to take into account this interaction.

- Section 8, Annual Energy Cost Criteria--Provides procedures for estimating the annual energy cost for residential dwelling units.

C. SUMMARY

There are three major differences between the old and new standard. First, the new standard is based on economics while the previous is not. Second, the standard incorporates the effects of cooling into the energy calculations. Third, the format of the standard has changed from one consisting of equations to a user friendly system of charts and tables requiring no calculations. This will definitely ease the job of the building code official in enforcing the building code and in the planning and construction of the residences for the contractor. The HVAC equipment to be selected in the construction of a building was originally to be based on the economics used in the standard. This was changed when Congress passed into legislation a law that required all HVAC equipment and electrical appliances meet specified energy efficient product standards. ASHRAE has been working on this particular standard for over four years. Its development has required great resources and the dedicated work of those at ASHRAE and the National Bureau of Standards. The techniques and procedures outlined in the guide could very well be an

essential step in developing future standards and revising existing ones.

IV. OUTCOMES AND FINDINGS

A. SUMMARY

This study was undertaken to determine how, and to what extent, life cycle costing is used in the development of voluntary consensus standards. In addition it set out to determine how much progress has been made in this area to date.

Before these issues were addressed, the organizations involved in developing voluntary standards were introduced in the first chapter. Among these organizations was ASHRAE, who is currently developing a standard based on life cycle costing. Standard 90.2, "Energy Efficient Design of New Low-Rise Residential Buildings," has been under development for more than four years. The standard prescribes the insulation values for the envelope of a building through the use of a simple system of charts and tables. This enables an individual such as a building code official to easily understand and enforce the building code.

To arrive at such a user-friendly standard was not an easy process. The committee spent a year just on developing the economics to be used in the consensus standard. The reason the process was so lengthy was due to the complexity of the economic model and the fact that this was a consensus standard. Theoretically, if a standard is a consensus

standard then the producers, users, and special interest groups have agreed on the level of the standard. This does not imply that the level the standard is set at is optimum. This can only be achieved by determining all life cycle costs and benefits for all parties affected by the standard. To achieve this the committee must be comprised of a representative cross section of all affected parties including the end user. This has proven to be a difficult task since most users lack the time and resources required to be a member of the voluntary standards committee.

The next chapter introduced the most common applications in life cycle costing. The Present Worth method was most highly recommended for decision criteria. Present and future costs are estimated and classified as either initial costs, recurring costs, or nonrecurring costs. Once these costs are defined they can be translated to a common point in time by reducing the stream of costs to a single number, where costs which are projected to occur in the future are discounted.

The ASHRAE committee found an essential factor to be the monetary savings produced from the reduction in the energy requirements of both heating and cooling as compared to the incremental modification costs to achieve greater thermal efficiency of the building envelope as shown in Appendix D. These costs were identified through the National Energy Model which used as its database the PEAR program developed by the Lawrence Berkeley Laboratories in California. Tests have

shown the data to have a high degree of comparison with actual costs.

The committee had considered including the selection of HVAC equipment in the calculations of life cycle cost but did not. During the course of review of the standard, Congress passed into legislation, a law requiring all HVAC equipment and electrical appliances meet specified energy efficient product standards. The committee decided that this would satisfy the equipment selection criteria of the standard.

While the law may prescribe minimum product standards it does not establish durability or quality requirements. This can lead to a significant nonrecurring cost. For example, equipment with the same efficiency rating can have different initial costs. An individual can buy the cheaper equipment and think that he is saving money in the initial purchase. But in reality, his total outlays during the life of the less expensive equipment can exceed that of the more expensive equipment due to more frequent repairs and replacements. This is why life cycle costing is an important factor in determining the true overall cost.

In using life cycle costing in developing a standard it is understandable that there should be a reduction in total costs of construction. During an interview with one of the committee members of ASHRAE Standard 90.2, a question was posed: What is the expected reduction in total costs of a project between the prior standard and the new standard? He

conveyed that initial estimates had produced a 10 to 20 percent reduction in costs. Since the standard is not expected to be released until the spring of 1989, it has not been possible to perform an impact study to show the correct percentage reduction.

B. CONCLUSION

Standard writing organizations should be aware of the errors that can be made in simply increasing up-front costs and ignoring nonrecurring costs that could have a significant impact in the decision process. [Ref. 1:p. 87] Life cycle costing provides the means for a proper economic analysis if applied correctly. A major concern in the economics of the standard is that the true time preference or discount rate may be incorrectly assumed. A higher rate of 25 percent is believed to represent those families of lower incomes. These are families that usually rent in lieu of buying a home and generally do not save their income. But more importantly, life cycle costs can appear to be lower by increasing up front investments or acquisition costs, leading to a reduction in maintenance or ownership costs. So if the new standard reduces the overall life cycle costs by reducing the monetary outlay for energy costs, the initial costs could be considerably higher to create a more energy efficient home.

It appears that the committee is not holding "effectiveness" constant. The adoption of the new standard into the building code could drive up the initial cost of a home,

preventing low income families from purchasing a new home and forcing them to live in greatly inferior dwellings. Even though the total cost over a 30 year life cycle period is lower under the new standard, the new home buyer will rarely benefit from the energy cost savings if he only owns the home for five to ten years. This runs contrary to the government's efforts in increasing the supply of homes available on the market. If families are prevented from buying a home due to its high initial cost, building contractors will respond by decreasing the production of new homes. This will reduce the stock of homes and lower the rate of substitution of new homes for old homes. A cost benefit analysis must consider how benefits to prospective product users are affected with any change in the temporal allocation of cost.

To properly evaluate the economic savings of the new standard, an impact study is recommended. The study should include an evaluation of the estimating techniques and the basic economic assumptions in the model. If the findings are favorable, the process used in developing ASHRAE Standard 90.2 could allow economic analysis of other standards. It is believed that with minor adjustments, the process previously outlined could be used to analyze design manuals used in the government. [Ref. 1:p. 95] It is evident that there is a move towards uniformity in developing construction standards. Once the format has been established, the review process can

be facilitated much easier and enable a structured process for economic analysis.

APPENDIX A

ASHRAE STANDARD 90.2

Voting Members

1. Frank J. Powell, National Bureau of Standards
2. William R. Strzepek, Dow Chemical Company
3. Carl E. Adams, Tennessee Valley Authority
4. George B. Barney, Portland Cement Association
5. Lynn H. Bringhurst, Mountain Fuel Supply
6. T. Joseph Cardenas, McGraw Hill
7. Sally A. Hooks, EEI
8. Merle F. McBride, Owens-Corning Fiberglas
9. Kenneth D. Mentzer, Mineral Insulation Manufacturers
10. Bion Howard, NAHB Research Foundation
11. Herbert C. Skarbek, Air-Conditioning & Refrigeration Institute
12. John Talbott, U.S. Department of Energy
13. Bruce A. Wilcox, Berkley Solar Group

Non-Voting (Consulting) Members

1. Floyd Barwig, Slingersland NY
2. Peter H. Billing, National Forest Products Association
3. Steve Byrne, Lawrence Berkley Laboratories
4. Kevin Cavanaugh, National Concrete Masonry Association
5. Jeff Christian, ORNL Tennessee
6. Rich Davis, FMHA, USDA

7. Earl Ferguson, CSP, Inc.

8. David Goldstein, Natural Res. Defense Council Inc.

9. Adam J. Hinge, New York State Energy Office

10. Don Colliver, University of Kentucky

11. Art W. Johnson, Gaithersburg MD.

12. Fred J. Keller, Carrier Corporation

13. Richard Kutina, American Gas Association

14. Esher Kweller, U.S. Department of Energy

15. Jerry E. Lawson, TPI Corporation

16. G. Patrick Payne, Payne Associates

17. Steve Peterson, National Bureau of Standards

18. James A. Ranfone, Gas Appliances Mfrs. Association

19. James S. Reilly, Philadelphia Electric Corporation

20. Ronald Ritschard, Lawrence Berkley Laboratories

21. Henry Rutkowski, HTR Engineering

22. Frank A. Stanonik, GAMA

23. Clifford D. Smith, Owens-Corning Fiberglas

24. Chris Thomaidis, Department of Housing & Urban Development

25. Adrian Tuluca, Steven Winter Association

26. Jose Villanueva, Florida Atlantic University

27. Frank Walters, Manufactured Housing Institute

28. Allen Weidman, American Bar Association

29. John Woodworth, Hydronics Institute

30. Hofu Wu, Arizona State University

APPENDIX B

CORRELATING VALUES

TABLE 3.1

R-SQUARE VALUES FOR LBL REGRESSIONS CORRELATING LOAD SAVINGS WITH WEATHER PARAMETERS

No. Description	HDD65	CDD75	CDH72	CDH74	CDH76	CDH78
1--R-11 Attic	0.9968	0.8825	0.9476	0.9657	0.9651	0.9383
2--R-11 Walls	0.951	0.7953	0.8852	0.9046	0.9055	0.8811
3--R-19 Attic	0.9979	0.8817	0.9333	0.9609	0.9709	0.9546
4--R-S,2ft Bsmt	0.9916	0.9601	0.9899	0.9895	0.9879	0.9853
4--R-S,2ft Slab	0.9888	0.9224	0.9387	0.9476	0.927	0.8724
5--Double Window	0.9863	0.9211	0.9674	0.9472	0.902	0.8311
6--R-30 Attic	0.9975	0.9345	0.9767	0.9873	0.9772	0.9402
7--R-5,4ft Bsmt	0.9871	0.8673	0.9561	0.952	0.9467	0.9405
7--R-5,4ft Slab	0.9916	0.8144	0.847	0.8271	0.7802	0.7063
8--Double SGD	0.9863	0.9235	0.9682	0.9485	0.9039	0.8335
9--R-13 Walls	0.9964	0.8883	0.9567	0.9641	0.9503	0.9098
10--R-38 Attic	0.9976	0.8923	0.9497	0.8671	0.9652	0.9366
11--R-19 Walls	0.9937	0.8789	0.9507	0.9592	0.9465	0.9071
12--Triple Window	0.9847	0.8728	0.9396	0.9324	0.9024	0.8473
13--R-48 Attic	0.9937	0.8985	0.954	0.9714	0.9693	0.9405
14--R-23 Walls	0.9902	0.8777	0.9547	0.9521	0.9266	0.8748
15--Storm Door	0.9507	0.7891	0.8822	0.9001	0.8993	0.8734

TABLE 3.2

HEATING AND COOLING LOAD FACTORS
FROM LBL PEAR ANALYSIS

No. Description	HLF	CLF
1--Frame Walls	21.19	1.0025
Masonry Walls		
2--Core Insulation	20.97	0.7219
3--Cavity	21.1	0.7262
4--Exterior Insulation	21.63	0.8269
5--Interior Insulation	20.02	0.7391
6--Core Ins. HC = 6	20.86	0.7184
7--Core Ins. HC = 9	20.56	0.6172
8--Cavity Wall HC = 6	20.86	0.7184
9--Cavity Wall HC = 9	20.56	0.6172
10--Exterior Ins. HC = 6	21.41	0.8186
11--Exterior Ins. HC = 9	21.11	0.754
12--Interior Ins. HC = 6	21.35	0.7885
13--Interior Ins. HC = 9	21.02	0.7074
14--Log Walls	21.13	0.8059
15--Ceilings--All	25.87	1.9787
16--Ceilings--Truss	25.91	1.9831
17--Ceilings--Cathedral	23.18	1.7022
18--Band Joist	21.09	0.9249
19--Doors	21.19	1.0031
20--Fenestration--Conduction (U)	20.29	0.2362
--Solar (SC)		
North	-2.52	1.1767
East	-4.02	1.8444
South	-9.93	1.845
West	-5.49	2.4188
Prototype	-5.49	1.8212
2--Core Insulation		

APPENDIX C

EQUIVALENT FULL LOAD HOURS

City	HDD65	CDH74	Full Load Hours Heat	Full Load Hours Cool
Albuquerque	4414	15538	659.6	2851.4
Bismark	9075	6861	1376.1	1399.5
Boston	5593	5413	870.7	1425.3
Brownsville	609	34029	53.1	4393.3
Charleston	2147	16473	182.5	2655.4
Fort Worth	2301	34425	236.6	2817.5
Jacksonville	1402	25200	108.0	3034.4
Los Angeles	1595	2416	0.0	2563.5
Miami	199	32951	1.6	4973.1
Minneapolis	8007	6344	1238.6	1370.8
Nashville	3756	17728	524.1	2180.5
New Orleans	1490	23546	130.0	3376.1
New York	4922	8337	793.0	1677.3
Phoenix	1442	52408	206.3	3535.3
Sacramento	2772	14026	403.5	2328.2
San Diego	1284	2514	0.0	2720.6
San Francisco	3161	843	0.0	2032.7
Seattle	4681	1222	722.2	941.5
St. Louis	4938	16302	769.7	2006.9
Tampa	739	26167	17.7	4124.4

APPENDIX D

SYSTEM OF EQUATIONS

Heating and Cooling Energy Cost Savings ≥ Modification Costs

or

$$FYS_h * P_h * S_h + FYS_c * P_c * S_c \geq FC * S_2$$

which on a square foot basis is

$$FYS_h = \frac{\text{delta U} * HLF * HDD65}{AFUE}$$

$$FYS_c = \frac{\text{delta U} * CLF * CDH74}{SEER}$$

Combining the above equations produces:

$$\frac{(\text{delta U})(HLF)(HDD65)(P_h)(S_h)}{AFUE} = + \frac{(\text{delta U})(CLF)(CDH74)(P_t)(S_t)}{SEER}$$

$$\geq (FC)(S_2)$$

This represents the complete equation used to set the criteria.

Conversion factors have been intentionally omitted from all equations throughout the appendices.

The calculated values of HDD65 and CDH74 are called intercepts and appear on the criteria curves as the points

were the lines intersect the horizontal and vertical axis. These equations are:

$$HDD65 = \frac{FC * AFUE}{delta\ U * HLF * P_h * (S_h/S_2)}$$

$$CDH74 = \frac{FC * SEER}{delta\ U * CLF * P_t * (S_t/S_2)}$$

where:

FYS_h	=	First Year Savings for Heating;
delta U	=	Incremental Change in U values for Materials;
HLF	=	Heating Load Factor;
HDD65	=	Heating Degree Days to Base 65 F;
P_h	=	Price of Fuel for Heating;
S_h	=	Economic Scalar for Heating;
AFUE	=	Annual Fuel Utilization Factor;
FYS_c	=	First Year Savings for Cooling;
CLF	=	Cooling Load Factor;
CDH74	=	Cooling Degrees Hours to Base 74 F;
P_c	=	Price of Fuel for Cooling;
S_c	=	Economic Scalar for Cooling;
SEER	=	Seasonal Energy Efficiency Ratio;
FC	=	Incremental First Cost of Materials;
S_2	=	Economic Scalar for Materials;
S_h/S_2	=	Economic Scalar Ratio for Heating;
S_c/S_2	=	Economic Scalar Ratio for Cooling.

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